Chapter 4

Forces and Newton's Laws of Motion

Examples of **Nonfundamental Forces** --
All of these are derived from the electroweak force:

<u>normal or support forces</u>

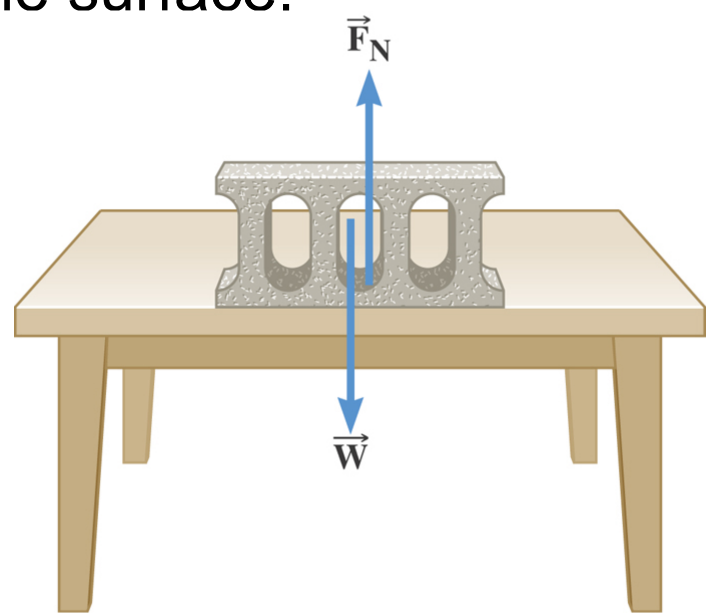
<u>friction</u>

<u>tension in a rope</u>

Definition of the Normal Force

The normal force is one component of the force that a surface exerts on an object with which it is in contact – namely, the component that is perpendicular to the surface.

Weight is the downward force exerted by gravity on an object.



For a block of weight W sitting at rest on a table, from Newton's 2nd law:

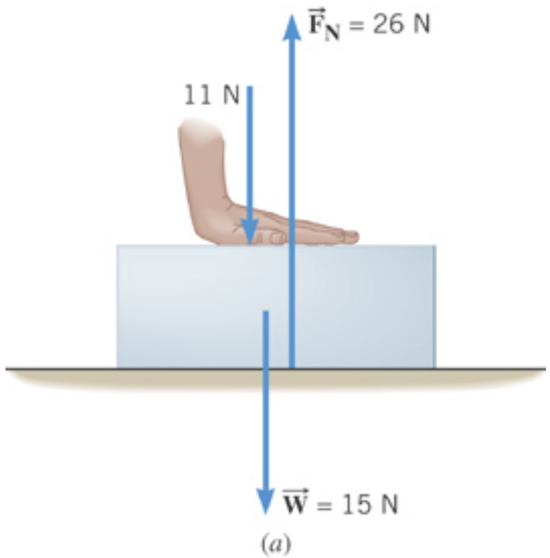
$\Sigma F_y = F_N - W = ma_y = 0$ --> $F_N = W$, and is directed upward

4.8 The Normal Force

$$\Sigma \vec{F} = \vec{F}_N + \vec{F}_H + \vec{W} = 0$$

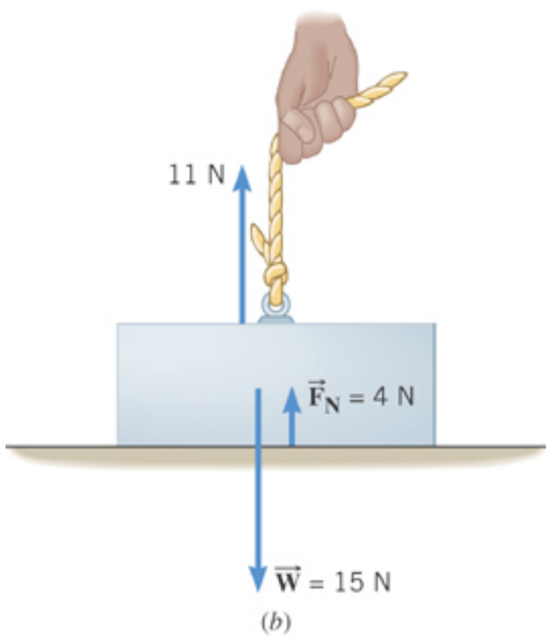
$$F_N - 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 26\text{ N}$$



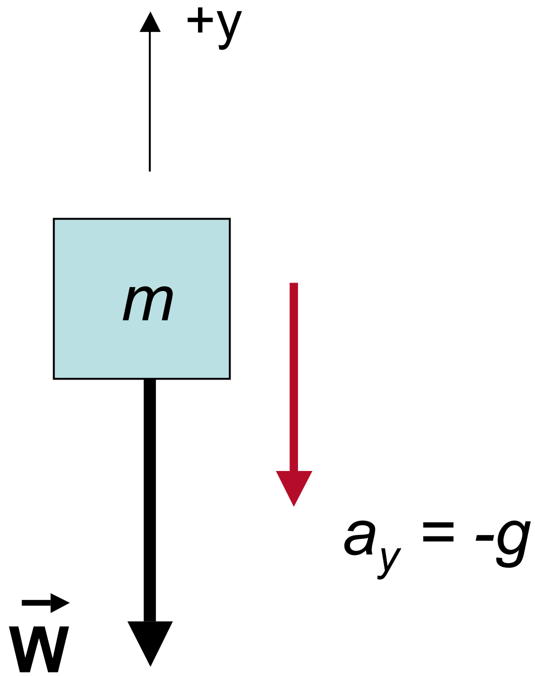
$$F_N + 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 4\text{ N}$$



4.8 The Normal Force

The *weight*, *W*, of an object can be associated with its *mass*, *m*, using Newton's 2nd law:



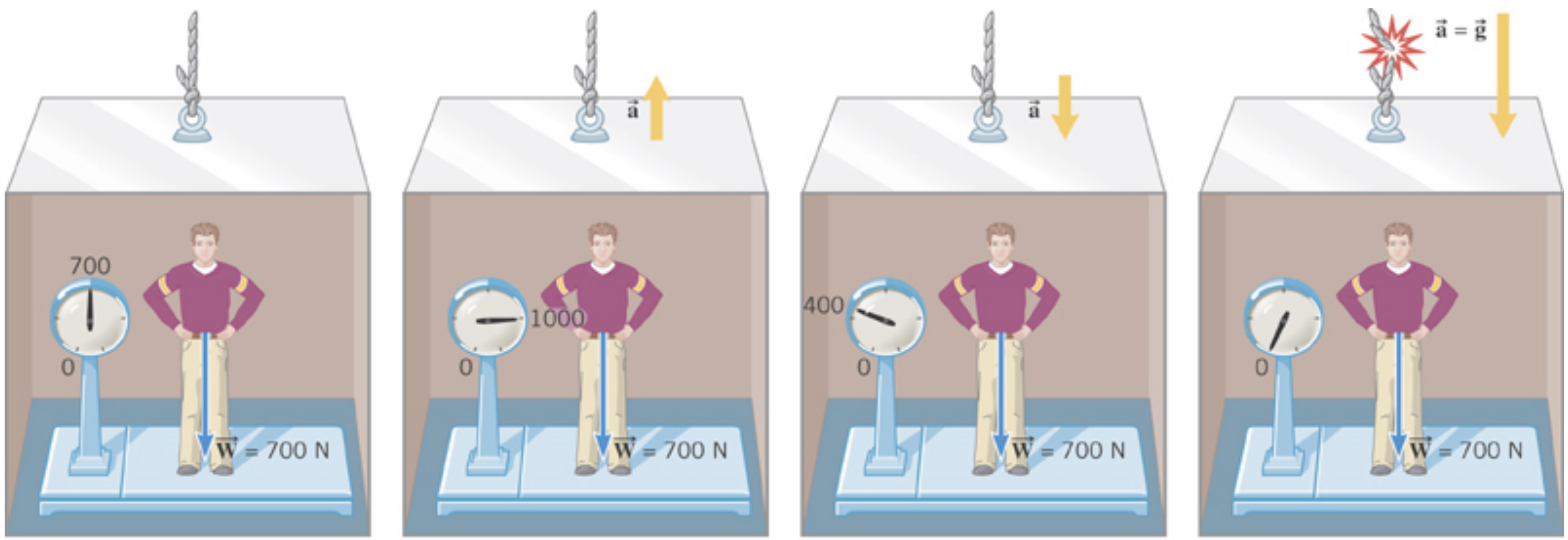
$$\Sigma F_y = -W = ma_y = m(-g)$$

$$\text{-->} \quad W = mg$$

Apparent Weight

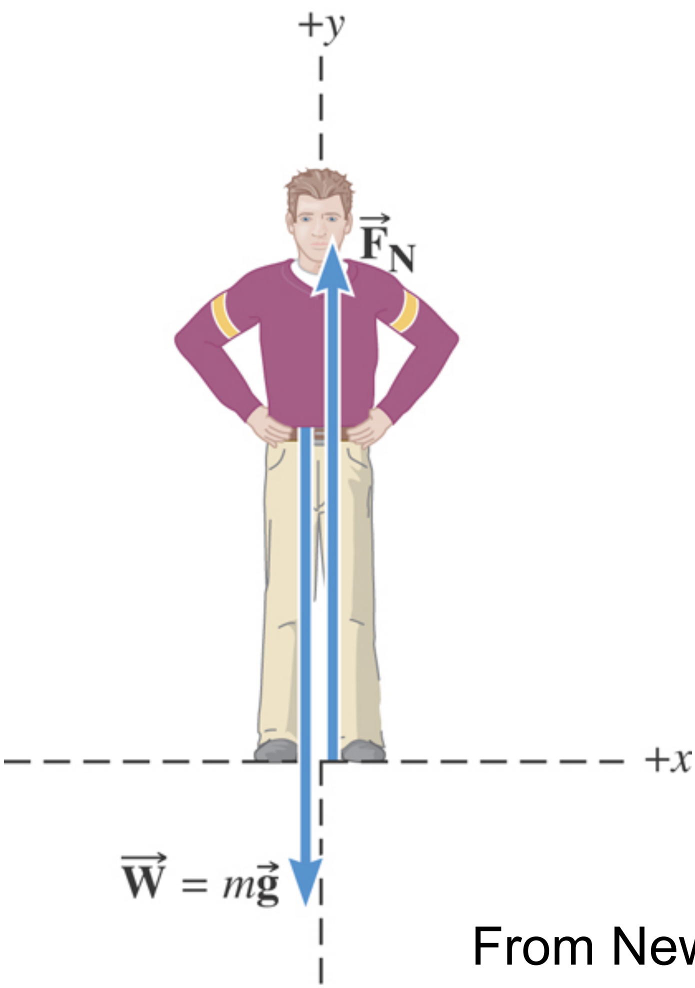
The apparent weight of an object is the reading of the scale.

It is equal to the normal force the scale exerts on the man.



(*a*) No acceleration ($\vec{v}$ = constant)   (*b*) Upward acceleration   (*c*) Downward acceleration   (*d*) Free-fall

4.8 The Normal Force



Sum of the forces acting on the man:

W

$$\sum F_y = +F_N - mg = ma$$

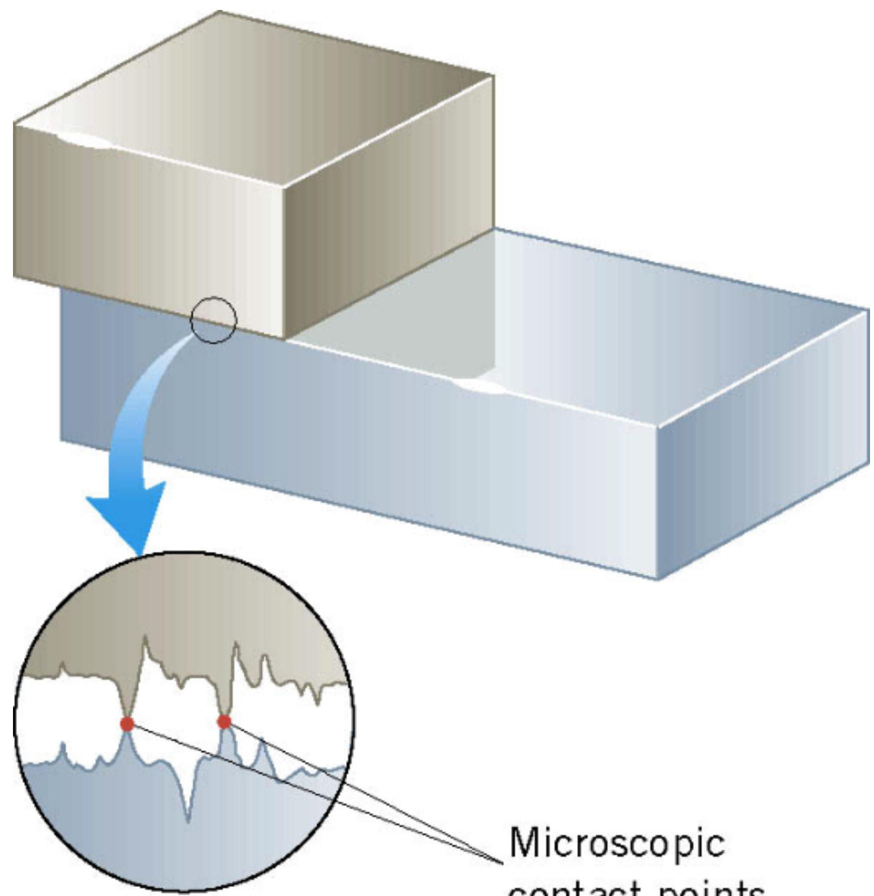
$$F_N = mg + ma$$

apparent weight (F_N) — true weight (mg)

From Newton's 3rd law:
the normal force exerted by the scale on the man is equal (and opposite) to the force the man exerts on the scale --> the man's apparent weight

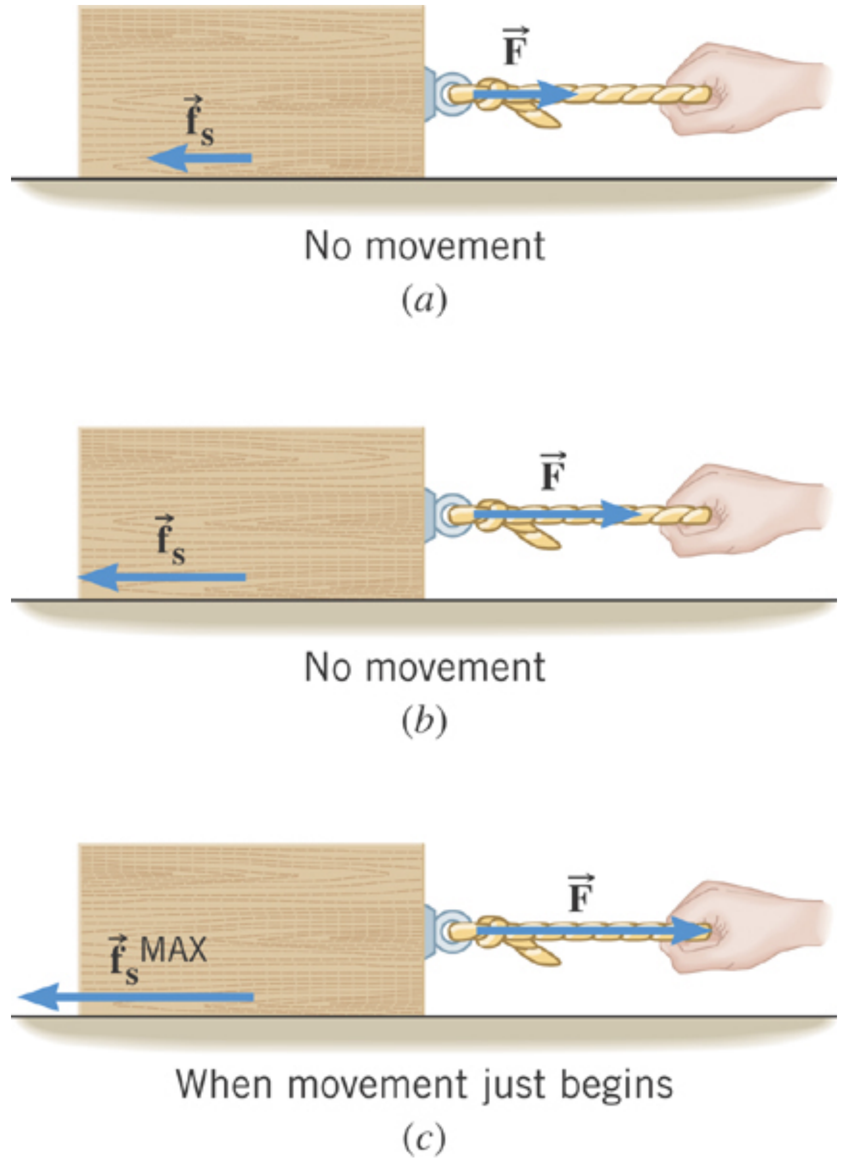
4.9 Static and Kinetic Frictional Forces

When an object is in contact with a surface there is a force acting on that object. The component of this force that is *parallel to the surface* is called the ***frictional force***.



4.9 Static and Kinetic Frictional Forces

When the two surfaces are not sliding across one another the friction is called ***static friction***.



4.9 Static and Kinetic Frictional Forces

The magnitude of the static frictional force can have any value from zero up to a maximum value.

$$f_s \leq f_s^{MAX}$$

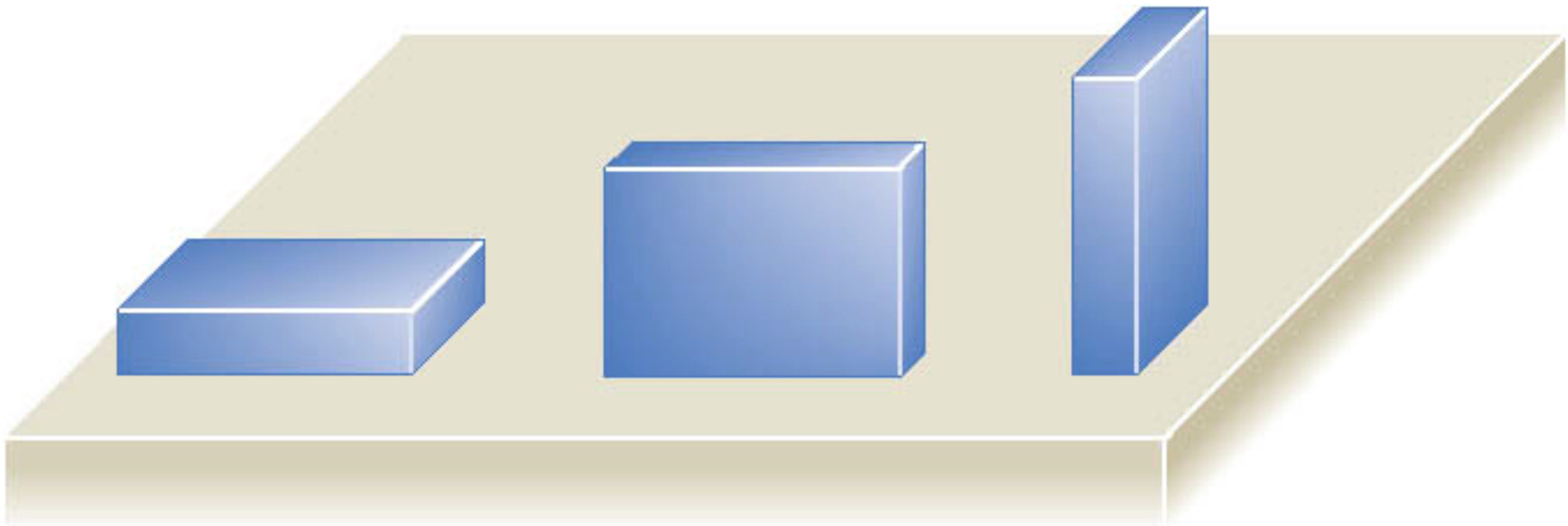
$$f_s^{MAX} = \mu_s F_N$$

Not a vector equation!
f_S is parallel to the surface,
F_N is perpendicular to the surface.

$0 < \mu_s < 1$ is called the coefficient of static friction.

4.9 Static and Kinetic Frictional Forces

Note that the magnitude of the frictional force does not depend on the contact area of the surfaces.



4.9 Static and Kinetic Frictional Forces

Static friction opposes the *impending* relative motion between two objects.

Kinetic friction opposes the relative sliding motion that actually does occur.

$$f_k = \mu_k F_N$$

$0 < \mu_k < 1$ is called the coefficient of kinetic friction.

4.9 Static and Kinetic Frictional Forces

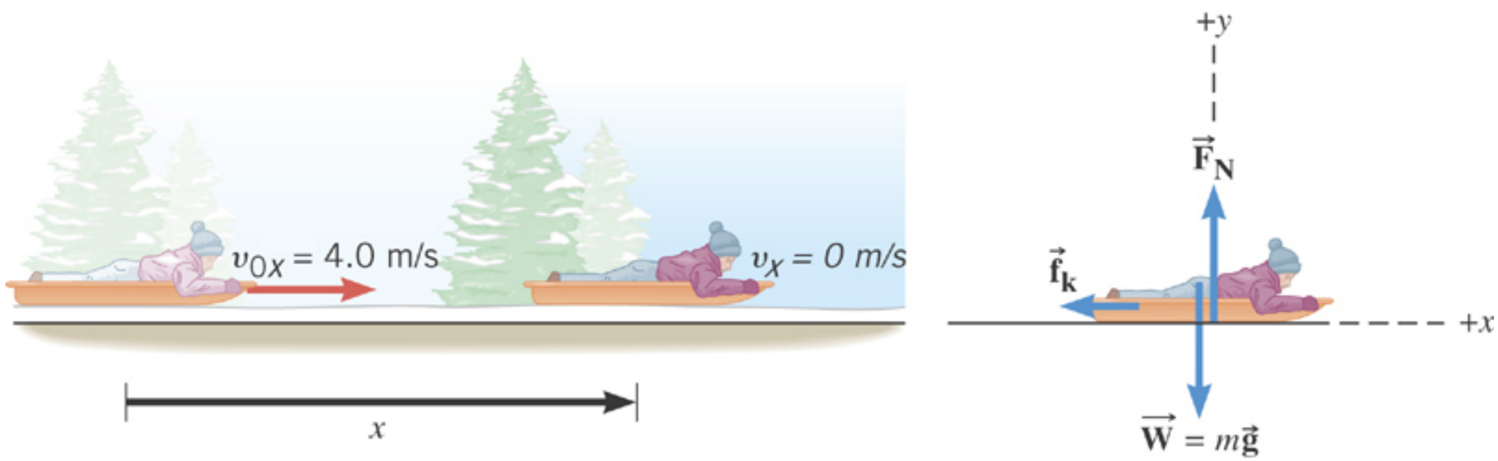
Table 4.2 Approximate Values of the Coefficients of Friction for Various Surfaces

Materials	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Glass on glass (dry)	0.94	0.4
Ice on ice (clean, 0 °C)	0.1	0.02
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on ice	0.1	0.05
Steel on steel (dry hard steel)	0.78	0.42
Teflon on Teflon	0.04	0.04
Wood on wood	0.35	0.3

Usually, $\mu_s > \mu_k$

4.9 Static and Kinetic Frictional Forces

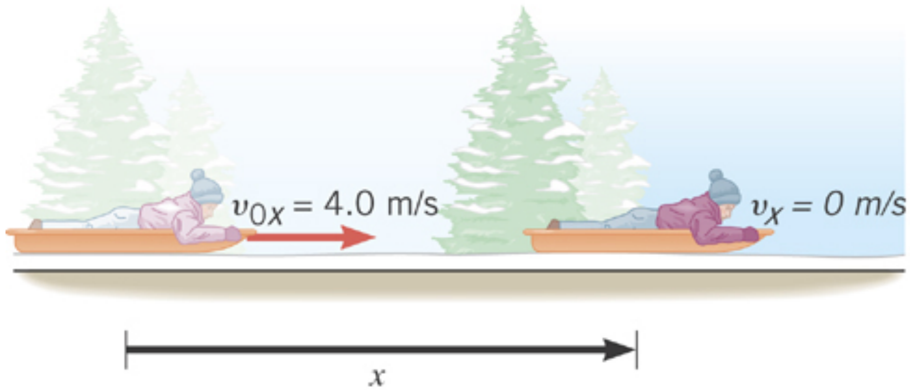
Example. A sled and a rider are moving at a speed of 4.0 m/s along a horizontal stretch of snow. The snow exerts a kinetic frictional force on the runners of the sled, so the sled slows down and eventually comes to a stop. The coefficient of kinetic friction is 0.050 and the mass of the sled and rider is 40 kg. Find the kinetic frictional force and the displacement, *x*, of the sled.



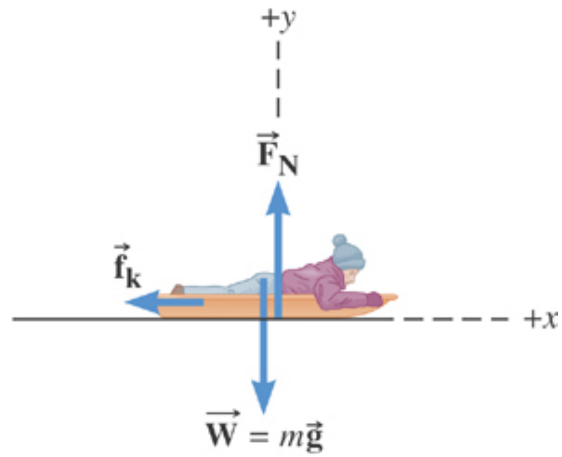
(*a*)

(*b*) Free-body diagram for the sled and rider

4.9 Static and Kinetic Frictional Forces



(a)



(b) Free-body diagram for the sled and rider

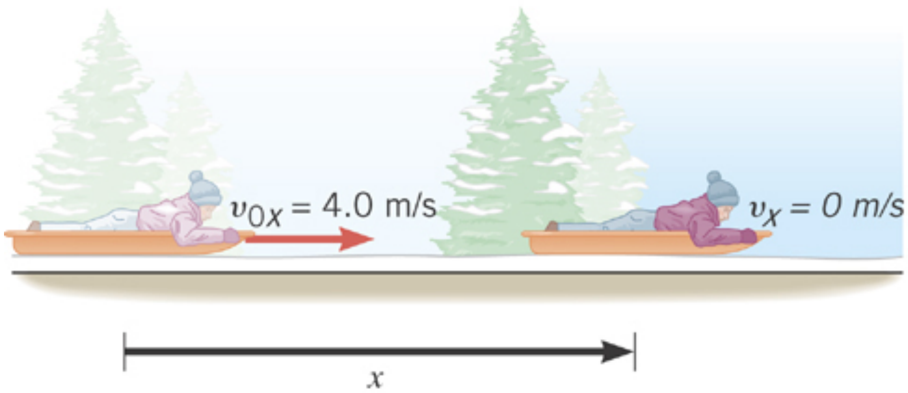
1. Use Newton's 2nd law in x and y directions.

$$\Sigma F_x = -f_k = ma_x \text{ --> } a_x = -f_k/m = -\mu_k F_N/m \quad \text{(since } f_k = \mu_k F_N\text{)}$$

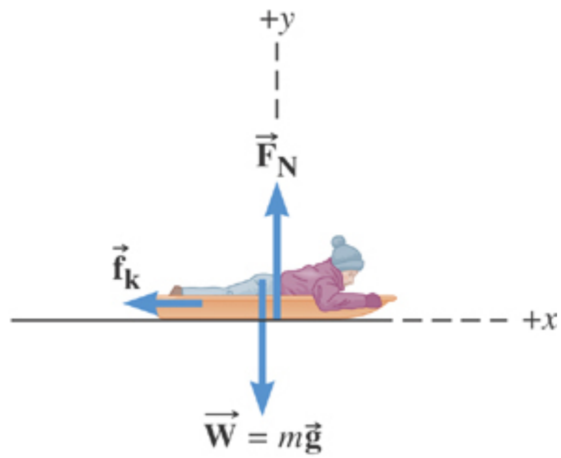
$$\Sigma F_y = F_N - W = F_N - mg = ma_y = 0 \text{ --> } F_N = mg$$

$$f_k = \mu_k F_N = \mu_k mg = (0.050)(40)(9.8) = \mathbf{20\ N}$$

4.9 Static and Kinetic Frictional Forces



(a)



(b) Free-body diagram for the sled and rider

$$a_x = -\mu_k F_N/m = -\mu_k mg/m = -\mu_k g = -(0.050)(9.8) = -0.49 \text{ m/s}^2$$

2. Solve for x using a_x and kinematic equations.

x	v_{0x}	v_x	a_x	t
?	4.0 m/s	0 m/s	-0.49 m/s^2	

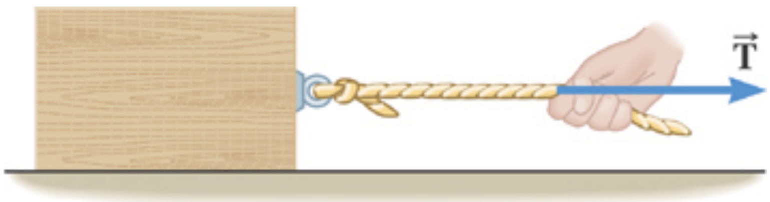
$$v_x^2 = v_{0x}^2 + 2a_x x \quad \text{-->} \quad x = (v_x^2 - v_{0x}^2)/(2a_x)$$

$$= (0^2 - 4.0^2)/(2(-0.49)) = \mathbf{16\ m}$$

independent of mass of sled+rider

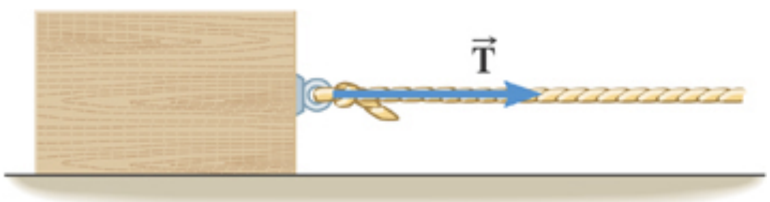
4.10 The Tension Force

Cables and ropes transmit forces through ***tension***.



(a)

A force $\vec{\mathbf{T}}$ is being applied to the right end of a rope.



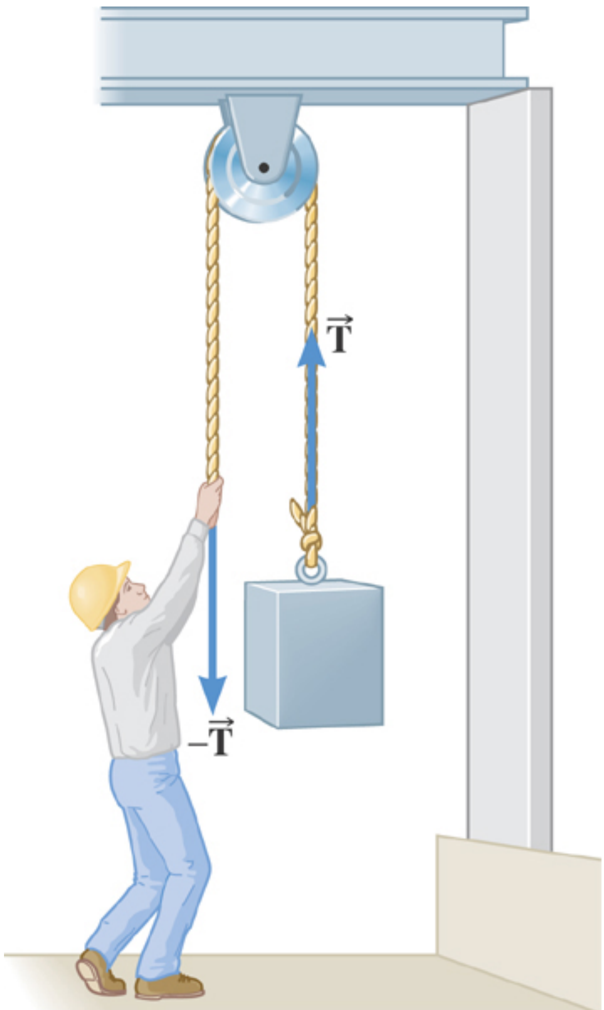
(b)

The force is transmitted to the box from the left end of the rope.

(c)

The box exerts an equal and opposite force to the left end of the rope via Newton's 3rd law.

4.10 The Tension Force



A massless rope will transmit tension undiminished from one end to the other.

If the rope passes around a massless, frictionless pulley, the tension will be transmitted to the other end of the rope undiminished.